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Progressive recovery of macrobenthic fauna in Chilika Lagoon after its restoration, with a focus on *Stenothyra blanfordiana* (Gastropoda: Stenothyridae)

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Original Article

Abstract

The macrobenthic fauna of Chilika Lagoon was investigated from July 2012 to June 2016 to comprehend the status post its restoration and to discern signs of biological recovery. The study revealed the existence of 42 macrobenthic faunal taxa belonging to 28 families, apart from polychaetes, oligochaetes and fishes. Gastropods dominated the macrobenthic population of the lagoon, especially in its Central sector during pre-monsoon and monsoon seasons. *Stenothyra blanfordiana* an endemic species with an abundance as high as 3067 no./m^2, contributed to 80% of the total abundance of the macrobenthic fauna. Despite its importance concerning global biodiversity, information on its ecology, habitat, feeding behaviour, etc. is seldom available worldwide. This study elucidated the distribution, habitat preference and behaviour of *S. blanfordiana* in Chilka Lagoon. This endemic species showed a preference for comparatively less sandy substratum with higher C:N values and exhibited a dietary preference for dead and decaying plankton, particularly prevalent in macrophyte-dominated regions. The study has also demonstrated the gradual recovery of the macrobenthic community within the ecosystem, particularly notable in the case of *S. blanfordiana*, from previously degraded conditions.

Keywords: *Endemic species, macrobenthic ecology, Chilika lagoon, lake restoration*

Introduction

Wetlands, as highly biodiverse and productive ecosystems, frequently undergo alterations, whether natural or anthropogenic, impacting the biodiversity they harbour. Ecologists advocate wetland restoration and ongoing ecological monitoring for adaptive management, ensuring ecosystem health (Buchsbaum and Wigand, 2012). Long-term monitoring of biota in response to environmental changes is vital for gauging the effectiveness of restoration efforts. Benthic invertebrates, a stable biotic component, are highly responsive to environmental changes over time (Cuffney *et al*., 2010). Endemic species are particularly vulnerable to localized human interventions, underscoring the importance of understanding their population dynamics and distribution. Chilika, Asia's largest coastal lagoon and a Ramsar site, hosts numerous endangered species listed on the IUCN Red List (Balachandran *et al*., 2005). Despite its ecological significance, the lagoon has suffered degradation due to loss of connectivity to the sea, persistent siltation, and decreasing depth (Mohanty *et al*., 2008, 2009). This degradation led to a substantial decline in biodiversity and richness. Following restoration efforts in 2000, reports suggest a revival in biodiversity, including fishes, macrophytes, plankton, and benthic fauna (Mohapatra *et al*., 2007; Mohanty *et al*., 2008, 2009). Despite this progress, benthic fauna remains one of the least studied macroorganism groups in the lagoon, with limited information available. Early studies by Kemp (1915), Patnaik (1971), Sarma and Rao (1980) and Subba Rao (1989) provided insights into the pre-restoration status of benthic fauna. However, post-restoration studies (Jayalakshmy and Rao, 2001; Ingole, 2002; Sahu *et al.*, 2007; Mishra and Mohapatra, 2016) primarily focused on quantitative and qualitative assessments, overlooking the functional significance of macrobenthos. This study thus aims to investigate the dynamics of the macrobenthic community and its functional role in the lagoon's ecology, particularly in the context of identification of an indicator species, *S. blanfordiana*.

Material and methods

Study area

The study was conducted in Asia's largest brackish water lagoon, the Chilika Lagoon, situated along the east coast of India, between lat. 19° 28'-19° 54' N and long. 85° 06'- 85°35' E, having a water spread of 1165 km^2. This shallow coastal lagoon with water depths ranging from 0.38 to 4.2 m, has been classified into four broad ecological sectors based on salinity gradient and depth *viz.*, the southern sector (saline), central sector (brackish), northern sector (freshwater due to riverine influx) and the outer channel (saline due to seawater influx) (Balachandran *et al.*, 2005). The study was based on samples collected from twelve stations spread across the four ecological sectors of the lagoon, namely, the Northern sector, Central Sector, Southern Sector and New mouth of the outer canal (Fig. 1). The lagoon receives continuous seawater influx through a narrow, 11 km long, canal (Station 1 in Fig. 1) and direct opening to the sea, which is a man-made opening created in September 2000 to restore the ecology of the lagoon (Station 8 in Fig. 1).

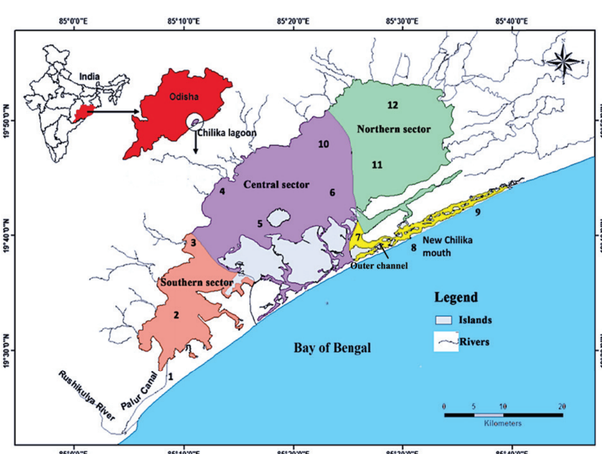

Fig. 1. Map of Chilika Lagoon showing the locations of sampling stations (1 to 12) under different ecological sectors (Northern sector, Central sector, Southern sector and Outer channel)

Data collection

The lagoon was sampled on quarterly intervals from July 2012 to June 2016 from 12 stations under the four ecological sectors for macrobenthic biota as well as soil parameters like pH, Specific conductivity, Organic carbon (%), Total nitrogen (%), Available nitrogen (mg/100g), Available P_2O_5 (mg/100g) and soil composition. Macro-benthic biota was sampled using Ekman dredge of grab area 0.023 m^2 per operation, covering the four ecologically different sectors of the lagoon (Fig. 1). Replicate grab samples were collected (total samples collected across all stations= 197) and combined for each ecological sector to obtain the average microbenthic faunal diversity and abundance. Taxonomic identification and nomenclature of the specimens were based on standard keys and literature (Subba Rao, 1989; ZSI, 1995). Macrobenthic abundance was calculated based on the recorded species diversity and their respective densities across different sectors and seasons. Abundance (no./m^2) was estimated as N= , where N= number of macro-organisms in 1 sq.m; n= number of macro-organisms per sampled area; a= area of Ekman dredge in sq. m. and h= number of grabs (number of grabs samples taken). The physicochemical parameters of the soil were assessed following (Eaton *et al.*, 2005).

Data analysis

To assess spatial variation in the macrobenthic community, species abundance data from the twelve stations were categorized according to ecological sectors. Stations 1, 2, and 3 represented the Southern sector, stations 4, 5, 6, and 10 were designated for the Central sector, stations 7, 8, and 9 were allocated to the Outer channel, and stations 11 and 12 were assigned to the Northern sector. Additionally, sampling months were grouped into three seasons such as pre-monsoon (March to June), monsoon (July to October), and post-monsoon (November to February). ANOVA test was conducted using 'R' software (R Core Team, 2019) to investigate the notable variances in macrobenthic abundance, the abundance of *S. blanfordiana*, and soil physicochemical parameters. Principal Component Analysis (PCA) was utilized to explore the relationship between soil parameters and the distribution patterns of *S. blanfordiana.*

Results and discussion

A total of forty-three species of molluscan macrobenthic fauna, representing 28 families, were documented. Additionally, the presence of polychaetes, oligochaetes, arthropods, and fishes was also recorded (Table 1). ANOVA analyses revealed no significant seasonal or sectoral variations in total macrobenthic abundance (Table 2). However, group-wise

Table 1. Spatio-temporal variation in abundance of macrobenthic fauna in Chilika Lagoon

	Abundance (no./m^2)											
Group/ Family and Species	Pr,_S	Pr,_C	Pr,_O	Pr,_N	M,_S	M,_C	M,_O	M,_N	Po,_S	Po,_C	Po,_O	Po,_N
Gastropods												
Potamididae												
Pirenella cingulata	171	156	277	99	141	143	430	88	92	242	202	22
Telescopium telescopium			22									
Nassaeriidae												
Nassarius stolatus	185	425	147	84	320	375	90	94	132	260	62	61
Thiaridae												
Tarebia granifera				81	110	55		37				88
Mieniplotia scabra				22		22						
Melanoides tuberculata		55	176	129	37	231	154	94		22		160
Stenothyridae												
S. blanfordiana	88	22				14916		44		264		
S. minima		48224						44		858		
Viviparidae												
Idiopoma dissimilis				22		22						
Filopaludina bengalensis	22			22				22				44
Naticidae												
Paratectonatica tigrina							22					
Natica vitellus			44									
Neritidae												
Nerita balteata							22					
Vittina smithi			22									
Trochidae												
Umbonium vestiarium			154				33					
Marginellidae												
Persicula persicula		154			22	22				22		
Melongenidae												
Volegalea cochlidium	22				22	22			22			
Lymnaeidae												
Racesina ovalior								22				
Racesina luteola				44								
Columbellidae												
Astyris lunata					264							
Bulinidae												
Indoplanorbis sp.				22				22				
Epitoniidae					88							
Bithyniidae												
Bythinia sp.		176										
Bivalvia												
Mytilidae												
Byssogerdius striatulus	224	252	22	128	128	296	781	79	22	1785	110	44
Brachidontes undulatus	88	92		22		44				22		154
Perna viridis			66									
Corbiculidae												
Corbicula striatella	22			44		308		22		726		121
Corbicula sp.		191		132		594		22		352		
Nuculanidae												
Saccella commutata		255		66		161	77			183		110
Nucula mitralis								264				

	Abundance (no./m²)											
Group/ Family and Species	Pr,_S	Pr,_C	Pr,_O	Pr,_N	M,_S	M,_C	M,_O	M,_N	Po,_S	Po,_C	Po,_O	Po,_N
Ennucula convexa		88				139	22	55				
Solenidae												
Solen vagina		51	66	264	22	506	44	704	44	55	22	55
Semelidae												
Theora opalina	22	62	44	55	44	128	22	176	44	92	33	
Tellinidae												
Psammacoma truncata	44	47		33	44	150			22	99		77
Psammacoma birmanica						220						
Mactridae												
Mactra grandis	22		719		22		176		66		638	
Mactra luzonica							22		22			
Veneridae												
Meretrix meretrix	66		22	44	33	88	88	110	22			
Trapezidae												
Neotrapezium sublaevigatum					44							
Laternulidae												
Exolaternula spengleri	44		22									
Unionidae												
Parreysia corrugata				22				22				22
Lamellidens marginalis								22				
Arcidae												
Anadara inaequivalvis		22										
Cuspidaridae						286						
Cuspidaria sp.		183							22	341		
Polychaetae	83	37	39	47	48	44	66	66	88		132	44
Oligochaetae	44		66	22	55	33	22	88		22		44
Arthopoda												
Mysids												
Isopods	33	22										
Amphipods	22	116		22	22	22				143		
Stomatopods												
Chironomids						66						
Cumacea					44			33				
Other insects	66	84		792	22			88				22
prawn	44			44		22			33			22
Shrimps	22	44										
Fish			22	22								
Total	1312	50715	1908	2262	1532	18915	2071	2217	631	5489	1199	1089

Pr= pre-monsoon, M= monsoon, Po= post-monsoon, S= southern sector, C= central sector, O= outer channel, N= northern sector

abundance distributions highlighted gastropod dominance during pre-monsoon and monsoon seasons, while bivalves prevailed during the post-monsoon period, particularly in the central sector and outer channel. Seasonal fluctuations in group dominance were observed, with *S. minima* dominating pre-monsoon, *S. blanfordiana* in monsoon, and *Modiolus striatulus*, alongside *S. minima*, in post-monsoon periods. Notably, *S. minima* and *S. blanfordiana* emerged as the most abundant species throughout the year, collectively constituting 80% of the total macrobenthic fauna abundance. The spatio-temporal abundance of the focal species *S. blanfordiana* in the present study showed no significant deviation (Table 2). Despite previous studies failing to elucidate the distribution and ecological significance of *S. blanfordiana*, our research underscored its importance as an endemic benthic species in India, particularly within Chilika Lagoon (Mishra *et al.*, 2013; Nevill, 1980). Notwithstanding its 'Least Concern' status by the IUCN (IUCN, 2023) due to its high abundance, its endemic nature renders it ecologically significant, emphasizing the lagoon's importance as its habitat (Ranjan, 1965). Given the limited data available, this brackish water species *S. blanfordiana* (Fig. 2) that lacks comprehensive investigation

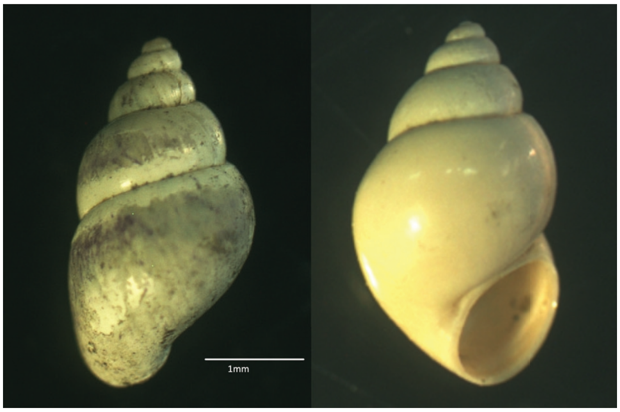

Fig. 2. *S. blanfordiana* recorded from Chilika Lagoon

encompassing distribution, biology, population dynamics, ecological trends, habitat preferences, and potential threats (Budha *et al*., 2010) was selected for the present study. Previous reports of *S. blanfordiana*, including its synonym *S. chilkaensis*, registered an early presence in the lagoon, particularly in the central sector (Preston, 1914). While macrobenthic faunal diversity was observed to be highest in the northern sector, the central sector exhibited maximal abundance, particularly of gastropods, during the pre-monsoon period (Table 1), aligning with findings from previous studies (Mohanty *et al*., 2009). *S. blanfordiana* displayed peak abundance during the monsoon and post-monsoon periods in the central sector, attributed to comparatively higher levels of total nitrogen, organic carbon, available nitrogen, and phosphate (Table 3). ANOVA results indicated significant seasonal variation in pH and available nitrogen, while spatial differences were significant across all measured soil parameters, except Available P_2O_5 and Free $CaCo_3$ (Table 2). Soil total nitrogen serves as a critical limiting factor for suspension feeder organisms (Tenore, 1988), while organic carbon, indicative of decaying organic matter, sustains deposit feeder benthic organisms. Consequently, the central sector of Chilika Lagoon has emerged as an optimal habitat for gastropods due to its favourable soil conditions. Despite the general categorization of *Stenothyra* spp. as decomposed matter feeders (Dudgeon, 1999), specific feeding behaviours of *S. blanfordiana* remain largely unexplored. To elucidate its distribution patterns, sediment parameters were subjected to Principal Component Analysis (PCA), revealing a significant influence of soil C:N ratio, organic carbon, and available nitrogen on *S. blanfordiana* population dynamics. With 55% of the variation in the *S. blanfordiana* population elucidated (Fig. 3 and Table 4), the findings underscored the significance of

Table 2. The P-values obtained from ANOVA to analyse significant spatiotemporal difference

Variables	Seasons	Sectors
Abundance. (no./m^2)	0.19000	0.61700
S. blanfordiana (no./m^2)	0.31000	0.56700
pH	0.00412	0.00019
Sp. Cond.(ohm)	0.09830	0.00031
Total N (%)	0.78185	0.00000
Avl. N (%)	0.02072	0.00000
Avl. P_2O_5 (mg/100g)	0.52094	0.14413
Org. C (%)	0.72238	0.00000
Free $CaCO_3$ (amu)	0.30986	0.20716

Table 4. PCA results to determine the effect of sediment parameters on *S. blanfordiana*

Parameters	Comp. 1	Comp. 2
Eigenvalue	0.35	0.21
Loadings (P)		
Available nitrogen (%)	0.529	
Available phosphate	0.212	-0.533
Organic carbon (%)	0.568	0.266
Carbon/Nitrogen	0.225	0.688
% Sand	-0.533	0.353

Table 3. Sector-wise soil parameters of Chilika Lagoon

Soil Parameters (Average value)	Northern Sector	Central Sector	Southern Sector	Outer Channel
Organic carbon (%)	1.23	1.89	0.81	0.70
Total nitrogen (%)	0.11	0.15	0.08	0.06
Available nitrogen (mg/100g)	17.78	22.02	18.19	12.73
Available P_2O_5 (mg/100g)	1.15	1.39	1.26	1.05
C/N	10.97	12.41	9.86	12.03
% Sand	63.69	49.00	76.81	60.33
% Silt	17.41	25.00	10.37	18.43
% Clay	18.90	26.00	12.82	21.20

the C:N ratio as a primary determinant of soil characteristics (Fig. 3). This relationship exhibited the highest loading (P= 0.69) along component 2, followed by organic carbon (P= 0.57) and available nitrogen (P= 0.53) along component 1 of the ordination diagram (Table 4). Furthermore, the deposition of dead and decaying plankton enriches sediment with carbon, thereby elevating the C:N values. This underscored the ecological importance of these parameters in shaping benthic community structure (Weckström *et al.*, 2017).

The lagoon's planktonic organic matter, particularly abundant in the central sector during the pre-monsoon period (Mohanty *et al.*, 2009; Mukherjee *et al.*, 2018), contributed to elevated organic carbon levels. Stenothyrids, equipped with radula for scraping plankton shells (Davis *et al.*, 1988), are likely to favour areas rich in dead planktonic matter, as indicated by PCA results. Historic records and present observations affirm the species' affinity for the central sector, corroborating its ability to exploit decaying planktonic resources, thus establishing a fundamental ecological niche (Preston, 1914; Devasundararn and Roy, 1954).

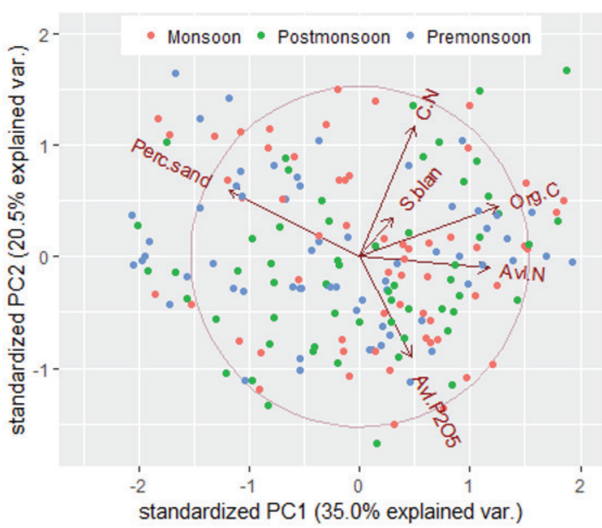

Fig. 3. PCA Ordination diagram explaining the relation between sediment parameters and abundance of *S. blanfordiana* over different seasons

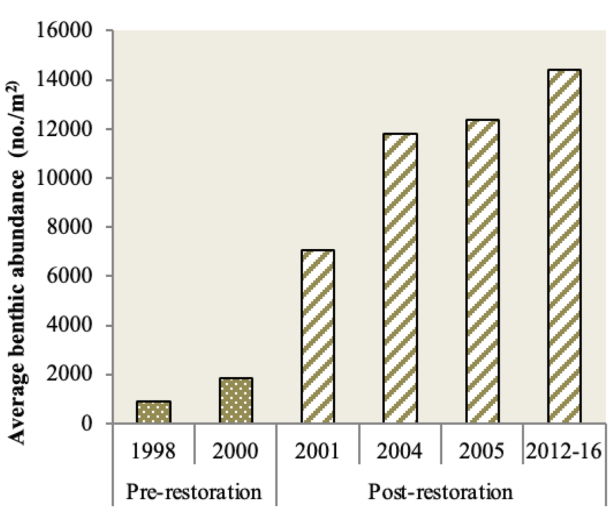

Fig. 4. Abundance of macrobenthic fauna from pre-restoration (1998) to post-restoration period (2000 to 2016) (Ref: Ingole, 2002; Mishra *et al.*, 2013)

The distribution range of *S. blanfordiana* in India spans coastal waters across West Bengal, Odisha, Tamil Nadu, and Andhra Pradesh, with a preference for sandy substrates (Dudgeon, 1999; Khan, 2003). However, our study revealed a negative correlation between *S. blanfordiana* abundance in Chilika Lagoon and sediment sand content, suggesting a preference for less sandy substrata within the lagoon. This preference aligns with the higher retention of organic carbon in less sandy soils, reinforcing the species' habitat selection criteria within the lagoon's brackish water environment.

The restoration of Chilika Lagoon in 2000 triggered an immediate increase in the abundance of macrobenthic fauna indicative of ecosystem recovery from siltation-induced degradation (Ingole, 2002). Despite the absence of data on macrobenthic fauna before 1998, changes in depth profiles over time have likely influenced benthic community dynamics, particularly in the central sector. The increase in lagoon depth post-restoration, coupled with altered sectoral depth regimes, has rendered the central sector more conducive to the production of benthic fauna, further fostering increased macrobenthic abundance. Continued enhancement in macrobenthic abundance post-restoration of the lagoon underscored the continued ecosystem recovery, with *S. blanfordiana* emerging as a potential indicator species for long-term ecosystem health monitoring.

Conclusion

The study revealed a diverse array of macrobenthic fauna in Chilika Lagoon. No significant seasonal or sectoral variations in macrobenthic abundance, including the target species *S. blanfordiana* however, *S. minima* and *S. blanfordiana* emerged as the most abundant species throughout the year, with the central sector being their major habitat owing to favourable environmental conditions. Historical data indicated an increase in macrobenthic abundance post-restoration, with the central sector exhibiting substantial recovery attributed to improved depth profiles and nutrient availability. This continued improvement underscores the lagoon's resilience and the efficacy of restoration efforts. Importantly, *S. blanfordiana* emerged as a potential indicator species for monitoring ecosystem health, emphasizing the significance of conservation initiatives in Chilika Lagoon.

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